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Rezagholi, Fatemeh; Hesarinejad, Mohammad Ali

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Integration of fuzzy logic and computer vision in intelligent quality control of celiac-friendly products

Fatemeh Rezagholi [a]*, Mohammad Ali Hesarinejad[b,c]

[a]*Department of Food Engineering, Near East University, Nicosia, via Mersin 10, Cyprus*
[b] *Department of Food Science and Technology, Ferdowsi University of Mashhad (FUM), PO Box 91775-1163, Mashhad, Iran*
[c] *Research Group for Food Production Engineering, National Food Institute, Technical University of Denmark, Søltofts Plads, 2800, Kgs. Lyngby, Denmark*

Abstract

Automation in food industry demands intelligent and feasible techniques to replace the human brain with machine intelligence. Quality control examines product attributes which cannot be quantified exactly and thus the relationship amongst the attributes parameters is unclear. The visual properties of the product can be more accurately and quickly examined by machine. Hence, in the present paper, a sensory evaluation was carried out on one of the main quality attributes as taste and was combined with two others as appearance and texture acquired by computer vision to determine the acceptable level of ingredients of a gluten-free cake (GFC). Analysis of samples using the aforementioned method indicated that acceptable levels of 50% purslane flour (PF) and 1% quince seed gum (QSG). Sensory evaluation indicated that the quality attributes can be ranked in a descending order as texture, taste and color. Employment of fuzzy logic and image processing was promising to indicate the optimum formulation of compounds as the top rank was found to be the third sample.

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Keywords: Image analysis; sensory evaluation; fuzzy logic; gluten-free cake; sensory evaluation.

* Corresponding author. Tel.: +90-533-832-3376; fax: +90-392-223-6461.
E-mail address: fatemeh.rezagholi@neu.edu.tr

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1. Introduction

Celiac disease is a genetically based autoimmune disorder affecting the gastrointestinal system and characterized life-long intolerance to the ingestion of gluten, which is prevalent in 0.71% (1 in 141) of adolescents and adults in the European country (Rubio-Tapia et al, 2012) Currently, the only effective and existing treatment for the disease is a life –long elimination of gluten – containing foods from the diet.

Some food additives such as gums have been widely used in the gluten- free food formulations to overcome these problem (Comes et al, 2007). The quince seed has a gum that was added to gluten – free cake formulation containing rice flour, purslane flour and another material. The physicochemical, sensory and transport properties of foods are largely dependent on crumb structure. Crumb structure affects appearance of crumb volume, color and texture of bakery product (Zghal Scanlon et al, 2002). Among the different classes of physical properties of bakery products, color is considered the most important visual attribute in the perception of product quality.

In recently year, automatic inspection in the based on machine vision technology has successfully been used for sensory evaluation of food and agriculture (Brosnan et al, 2004). Chandraratne and coauthors techniques used machine vision as well in the category of meat (Chandrarantne et al, 2007). Also Cubero the advantage of using machine vision techniques in automated inspection and reported quality evaluation of fruit and vegetables (Cubero et al, 2011). In another study Gonzales –Barron showed image processing and machine vision technique can as well be used to evaluate the characteristics of the bread crumb structure (Gonzales and et al, 2008).

Computer vision provides non-destructive method to objectively measure color patterns in non- uniformly colored surface, also determine other physical features such as morphological elements, image texture and defects. it is possible to extract visual features, such as texture, size, shape, and color being relevant for analysing a certain quality descriptor (Mendoza and Aguilera, 2004; Brosnan and Sun, 2003).

Traditional methods in determining the sensory evaluation food quality are used but these methods are time-consuming and costly to develop. These factors cause motivate for develop alternative methods in less time and with greater accuracy that evaluate the product specification. Image processing systems play a more and more important role in the food quality evaluation by maintaining accuracy and consistency while eliminating the subjectivity of manual inspection. The development of an image analysis system for determining the visual quality attributes of a cake is complicated by the vague linguistic descriptors often used by experts responsible for evaluating the product. One way of dealing with the discrepancy between the crisp numeric data output from image analysis and the more indefinite linguistic information from these experts describing a visual impression is to implement a fuzzy logic system. Fuzzy approaches have been successfully applied in many experiments that involved fuzzy data. Fuzzy logic is a very good candidate to replace the human perception in quality attributes measurements. Hence, in the present study, it was tried to proposed an affordable approach to further reduce the human intervention in the quality control of food products. In other words, the acceptable levels of ingredients were examined and evaluated for the optimum quality attributes.

2. Material and Methods:

2.1. Ingredients and preparation

Rice flour having 7.4 %, moisture, 10.48% protein, 1.01% ash, 0.82% fat, from the Dr. Oetker company in Izmir. Sugar (sucrose), salt and baking powder (Katsan, Quallette, Istanbul, Turkey). The entire egg from local market. Quince from local market and flour of purslane seed consumed from Iran-Bazr. The quince seed gum was extracted and purified according to the procedure described by Jouki et al, (2014). Preparation of the free gluten cake and baking according to the procedure described by Turabi et al, (2008) (See Fig.1).

2.4. Image analysis

The evaluation of crumb grain and crumb color of cake was performed using an image analysis system consisted of a canon digital camera (model SX60 HS, Japan) and a personal computer with a Pentium(R) Dual-core Processor

and Windows processor and Windows 7 Ultimate. The samples were photographed at a fixed distance of 30 cm from the crumb of samples, which were sitting inside a black box.

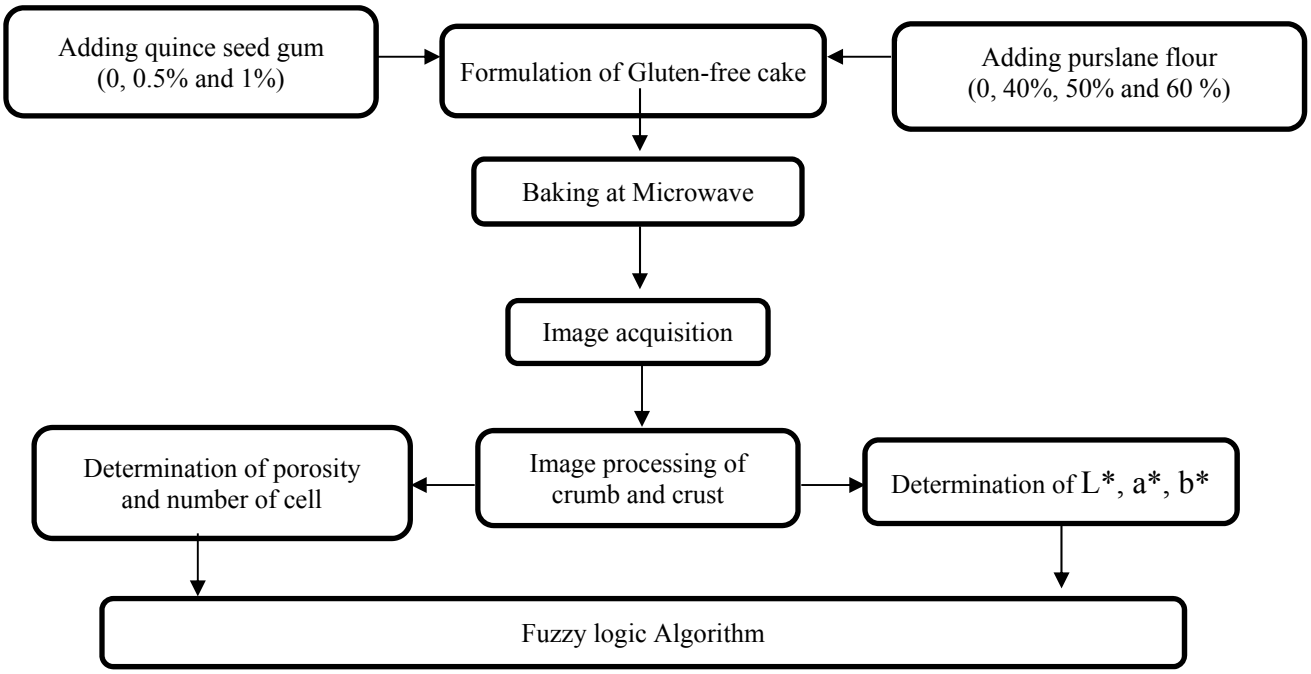


Fig.1. Gluten-free cakes preparation procedure and different formulations of cake.

2.4.1. The color spaces

For determine the color of crust was used color models CIE L^* a^* b^* (or CIELAB). Since the figure was captured in RGB color spaces, color spaces conversion operation done to obtain indexes CIE L^* a^* b^* after that three index were determine, L* that indicative the brightness of the image, a* that indicative the red (positive values) and green (negative values) and b* indicative yellow (positive values) and blue (negative values).

2.4.2. Crumb structure of cake

After imaging, each image was converted from RGB format to 8 bits (grey level) using a standard IP software package. In this format, an area of 3×3 cm^2 was selected at the center of the capture image. After contrast enhancement of image, the image segmented using the Otsu algorithm, which produces highly uniform binary image (Otsu, 1979). Finally, crumb grain properties of cake were studied by determination of total number of cells and porosity (total area ratio).

3. Results and Discussion

The main quality attributes of the gluten-free cake obtained by different methods were brought and discussed here. The crust texture and color determined using computer vision and the cake's taste obtained by conducting sensory evaluation.

3.1. Evaluating the color components of gluten-free cake crust

According to the results of table 1 the amount of component L^* of cake samples containing quince seed gum and purslane flour significantly decreased compared to the control samples ($p < 0.05$) so that there was a significant

difference between the sample containing the purslane flour and quince seed gum with the percentages of 0.5% and the control sample and also the samples containing purslane flour and quince seed gum with the percentages of 1% , mean's between the samples of cake have percent identical of purslane flour but percent of their gum is different there is a significant difference. In the same case, in a study on the effect of gums on the cake, Rikhtegari et al (2011) concluded that by adding the gum, the factor of lightness L^* significantly increases compared to those without gum that represents the brighter crust colors and is desirable (Rikhtegary and et al, 2011). On the other hand, by increasing the amount of purslane flour in the formulation of cake, the amount of L^* significantly ($p < 0.05$) decreased that is likely due to the low moisture content in the samples containing 40, 50, and 60 percent of purslane flour compared to the control sample. The decrease in the moisture content also is a factor in creating an uneven and wrinkle surface and has the capability of light reflection or the same L^* component.

Here, it seems that the increase in color component L^* originates from a smooth and uniform crust in the samples containing the quince seed gum that is as a result of slower transfer and migration of moisture from the core to the crust of cake. In this regard, Purlis and Salvadori (2009) stated that the changes in the bread surface are responsible for its brightness and regular and the regular and smooth surfaces are more capable of reflecting light and increasing component L than the wrinkle surfaces (Purlis and Salvadori, 2009).

On the other hand, according to the results of Table 1 the results of evaluating the color component a^* indicating the amount of cake crust redness show significantly an increase ($p< 0.05$). This means that with the samples containing purslane flour, the cake crust color will tend to be red. The increase in factor a^* is due to the presence of red pigment in the purslane seed skin and this factor also probably reduce the amount of b^*. Also, the cakes containing Purslane flour with more percentages of gum had less a^* than the cakes containing Purslane flour with less percentages of gum. This means that adding hydrocolloids causes reduction of the red tint in the samples containing the cake, considering that the interaction of hydrocolloids with water and water activity of product is affected and thus affects the process of changes in color parameters. Adding the hydrocolloids reduces the redness of crust that is considered as desirable in cake. In the study of the red component, Lazariou et al, (2007) and Mohammadi et al, (2013) concluded that adding hydrocolloids reduces the redness of crust color (Lazaridou et al, 2007, Mohammadi et al, 2013).

In addition, the results show that by increasing the amount of Purslane flour the component b^* was significantly ($p < 0.05$) reduced so that the highest amount of color component b^* was in the control and the lowest amount was in the sample containing 40% of purslane flour and 0.5% of quince seed gum. In this regard, in their study, Samuel et al (2004) reported that the color of Melon Seed flour is bright yellow that adding it to the formulation of the food product brightens the product color and increases the amount of component b^* that the results of the present study are reverse of the present results; it means that the color of purslane flour is dark brown that adding it to cake formulations darken the product color and decrease the amount of component b^* (Samuel and et al 2004).

Table 1. The effect of adding purslane flour and quince seed gum on crust color of gluten free cake

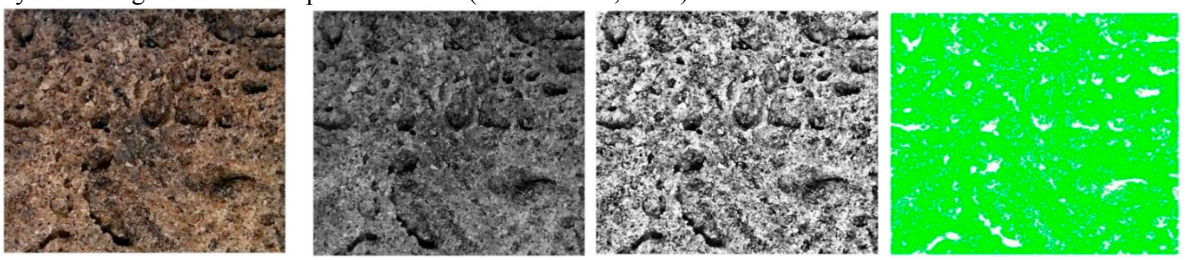
Treatments	Purslane flour %	Seed quince gum %	Crumb color properties		
			L*	a*	b*
control	0	0	55.57± 0.5^a	1.23±1^a	40±0.5^a
sample1	40	1	40.64± 0.21^c	3.19±0.1^c	12.27±0.7^b
Sample2	40	0.5	39.70±0.21^b	3.30± 0.2^c	12.17±0.5^b
Sample3	50	1	35.40± 0.16^c	3.73±0.0^c	12.38±0.8^b
Sample4	50	0.5	34.26±0.24^b	3.79±0.1^c	12.30±0.4^b
Sample5	60	1	32.18±0.23^c	4.20±0.1^b	12.46±0.6^b
Sample6	60	0.5	31.26±0.25^b	4.50±0.1^b	12.40±0.6^b

Means± SD in each column with different letters differ significantly in P<0.05

3.2. Crumb structure of cake

In this study, in order to computing indicators structure of crumb, levels of image processing (IP) contains the transfer color images to a standard IP package software, convert images from color (24bit) to from uniform gray

(8bit) improve the contrast of gray scale images, and finally segmentation of images and was convert images 8 bit to binary (Fig. 1). Insoluble fibers cause breakable point in the dough structure and cause facilitating escape of gases from their (Martines and et al, 2014). According to the results of the characteristics of cake core structure (Table 2), it was found that the number of cells in the samples containing the purslane flour significantly increased compared to the control sample ($p < 0.05$). However, by comparing the cakes containing purslane flour but with a different percentages of quince seed gum, the samples with higher percentage of quince seed gum have higher number of cells but by increasing the purslane flour with the amount of 60%, the number of cells in the sample containing 1% of quince seed gum decreases and has a significant difference with the sample containing 0.5% of quince seed gum and other samples ($p< 0.05$). Increasing the number of cells by increasing the quince seed gum can be due to the effect of gums on the stability of gas cells by forming a thick layer on the surface of cells. The presence of this layer on the surface will have more and smaller cells (Ozge ozkoc et al 2009). On the other hand, increasing the number of cavities in the texture center improves the structure of cake center. It was observed that the purslane flour at high levels decreased the capability of holding air bubble and the uniform dispersion of air cells in its development during the baking process due to the weakening of the starch network that was consistent with the results of Ghavidel et al (2013). By studying the images prepared from the internal texture of cake during the process test, the researchers found that the number of cavities and uniform dispersion of the gas cells within the network increased by increasing the amount of purslane seeds (Gavidel et al, 2014).



(a) (b) (c) (d)

Fig. 2. A typical digital image of free gluten cake crumb from a 3×3 cm^2 field of view:
a) the original image; b) Grays -level image; c) the contrast adjusted image; d) the binaries image

Another important parameter of cake center is the porosity of the cake that generally refers to the structure of cake pore and is considered one of the factors affecting the qualitative properties of the cake center (ARMERO COLLAR 1996). To convert gray images to binary, active the section of binary software (Fig. 2). These images consist of dark and light spots that the calculation of the ratio of light to dark spots is estimated by an index of amount porosity of samples. Obviously that whatever this ratio is high means amount of pores in texture of cake (amount of porosity) is more. Enabling section analysis software is measured ratio calculation and percent of porosity. Table 2 shows that the porosity in the samples of purslane flour containing quince seed gum significantly increased compared to control samples ($p < 0.05$).

Given the amount of porosity is directly related to the number of gas cells and more importantly, their uniform distribution in the texture of product (Ziobro et al, 2012). It is likely that the presence of purslane flour in the initial formulation of gluten-free cake with protein content provides the grounds for the gas cell wall strength and prevents its tear and also, due to the amount of enough fat in purslane flour, it contributes to the uniform dispersion of gas cells. Peighambardoust et al. (2011) reported that the purslane seed has more fat content than other of the herbaceous seeds, even wheat. On the other hand, the porosity significantly increased in the sample containing higher percentage of gum ($p< 0.05$). However, the amount of porosity significantly decreased in the samples containing 60% of purslane flour and 1% of quince seed gum that probably the negative interactions of fat in the purslane flour and quince seed gum led to decrease the porosity. The reason was high viscosity of dough and gel formation that as a result of it, the texture of cake dough was deteriorated for accepting a part of the incoming air bubbles during the process of mixing and its uniform dispersion and thereby the amount of porosity of final product decreased. The results of research conducted by Armero and Collar (1996) also showed that the hydrocolloids improve the water distribution and thus improve the texture of baking products by the effect on the starch structure

but their increase has the opposite result. The presence of starch network is due to adding purslane flour and quince seed gum. Moreover, examining the color components L*, a*and b*, adding purslane flour and quince gum further darken the color of cake.

Table 2. The effect of adding purslane flour and quince seed gum on Crumb grain properties gluten free cake

Treatments	Purslane flour %	Seed quince gum %	Crumb grain properties	
			porosity	Number of cell
control	0	0	37[a]	1918.5[a]
Sample 1	40	1	51[b]	3176[b]
Sample2	40	0.5	48[b]	2696b[b]
Sample3	50	1	56[b]	3526[b]
Sample4	50	0.5	53c	3275[c]
Sample5	60	1	50[d]	3168[d]
Sample6	60	0.5	59[c]	3671[c]

Means± SD in each column with different letters differ significantly in $P < 0.05$

3.2. Sensory of evaluation of free gluten cake samples

Sensory evaluation of cakes was carried out in 6 days. Seventy Judges were selected from students of Near East University, aged between 22 and 30. Evaluators were interested in sensory evaluation of cake. Scoring was carried out in a five points hedonic scale according to Table 3. Quality attributes including surface color and porosity of samples and overall acceptance. Each sample was randomly numbered and presented to panel members.

3.3. Fuzzy analysis of sensory data

It was observed that fuzzy logic approach could satisfactorily help classification of products by offering an easy – to-deploy approach with minimal computational load. The panelist responses were analyzed using common method of similarity approach presented by Mukhopadhyay et al, 2013 and Singah et al, 2012 and listed in Table 3.

Table 3. Normalized values for quality characteristics of seven samples. Texture and colour were acquired via computer vision; taste was obtained by similarity value from panellists (Mukhopadhyay et al, 2013)

	Sensory Scale	Color	Texture	Taste
Control	Not satisfactory	0.171	0.2	0.071
	Fair	0.314	**0.285**	**0.457**
	Satisfactory	0.285	0.257	0.285
	Good	0.228	0.257	0.128
	Excellent	**0.428**	0	0.057
Sample 1	Not satisfactory	0.014	0	0.014
	Fair	0.071	0.085	0.042
	Satisfactory	0.3	0.285	**0.471**
	Good	0.185	0.271	0.2
	Excellent	**0.428**	0.357	0.271
Sample 2	Not satisfactory	0.014	0	0.042
	Fair	0.071	0.114	0.128
	Satisfactory	0.085	0.285	**0.314**
	Good	0.185	0.228	0.271
	Excellent	**0.428**	0.328	0.242

Sample 3	Not satisfactory	0	0	0
	Fair	0.028	0.042	0.028
	Satisfactory	0.042	0.185	0.1
	Good	0.271	**0.214**	0.285
	Excellent	**0.657**	0.7	0.542
Sample 4	Not satisfactory	0	0	0
	Fair	0.042	0.057	0.071
	Satisfactory	0.071	0.157	0.1
	Good	0.314	0.171	0.257
	Excellent	**0.571**	0.614	0.571
Sample 5	Not satisfactory	**0.214**	0.257	0.1
	Fair	0.6	**0.482**	**0.442**
	Satisfactory	0.114	0.142	0.242
	Good	0.071	0.114	0.142
	Excellent	**0**	0.057	0.071
Sample 6	Not satisfactory	0.114	0.071	0.028
	Fair	**0.157**	0.214	0.314
	Satisfactory	0.6	**0.528**	**0.328**
	Good	0.1	0.114	0.214
	Excellent	**0.028**	0.071	0.114

Table 4. Ranking of quality attributes for seven samples

Sample ranking of quality attributes	
control	Color (excellent)>taste(fair) >texture(fair)
Sample 1	Color (good) > texture(excellent) >taste(satisfactory)
Sample2	Color (excellent) > taste (good) > texture(excellent)
Sample3	Color (excellent) > taste (excellent) > texture(excellent)
Sample4	texture(excellent) > taste(excellent) > texture (good)
Sample5	Texture (faire) > taste (fair) > color (not satisfactory)
Sample6	Texture (satisfactory) > taste (not satisfactory) > color (fair)

4. Conclusion

This study tried to propose an approach to further reduce the degree of food quality control independency to humans. The significant quality attributes of a food product as color and appearance were examined and measured by a machine and then the taste was quantified by sensory evaluation and added to the overall evaluations. Since these attributes have no clear relationship, soft computing techniques were employed to observe their degree of reliability.

The results were promising to a satisfactory extent. According to result of images analysis, adding purslane flour and quince seed gum cause improves the texture appearance through increasing the number of gases cells. Moreover the presented approach using similarity analysis implied that gluten-free cake could be optimally produced by following the acceptable levels of ingredients. In other words, by adding 1% quince seed gum and 50% purslane flour to the free-gluten cake, the desired results will be achieved and on the contrary, adding further purslane and quince seed gum flour and will deteriorate the cake's quality.

Sensory evaluation indicated that the quality attributes can be ranked in a descending order as texture (highly important) > taste (necessary) > color (somewhat important). Likewise, the quality attributes of the best composition of the cake was found out to be: texture (highly important) > taste (necessary) > color (somewhat important).

Finally, the samples could be accordingly ranked as sample3 (excellent) > sample2 (excellent) > sample4 (excellent) > sample1 (good) > sample 6 (satisfactory) > sample5 (fair).

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